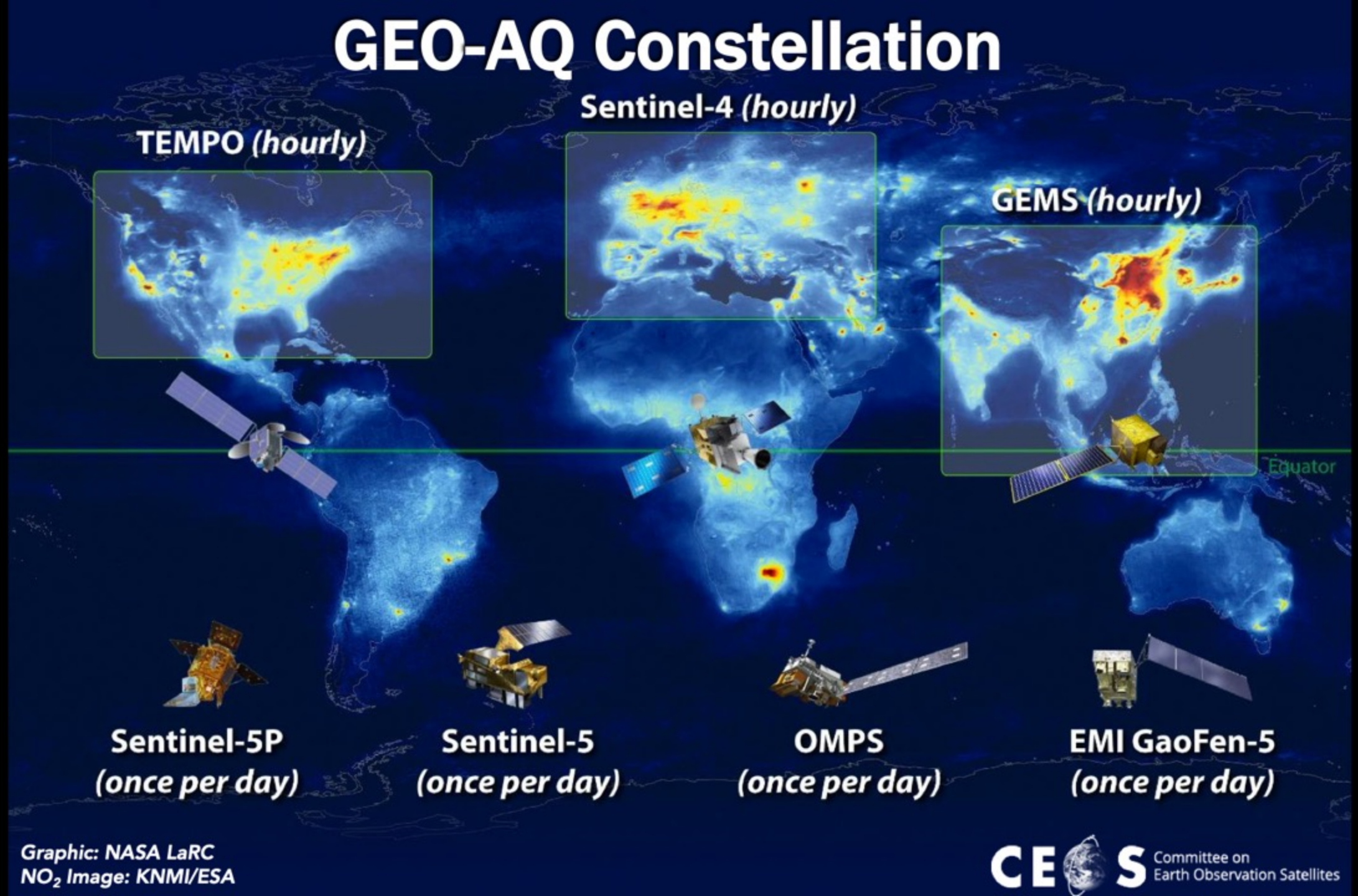
Connections to geostationary air quality observations during TRACER-AQ (Houston, TX: Sept 2021)

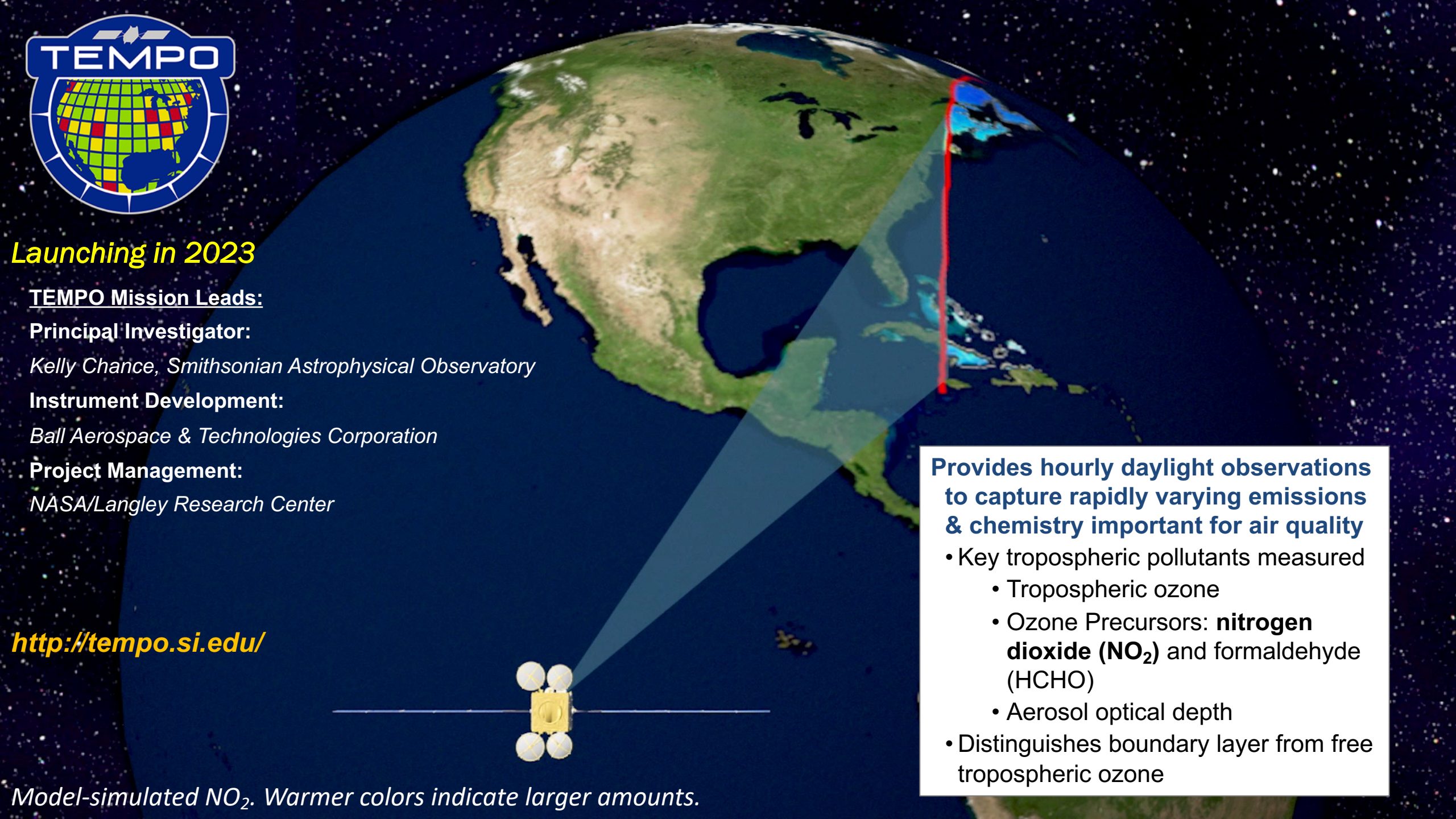
Laura Judd, NASA LaRC & John Sullivan, NASA GSFC
& the TRACER-AQ Science Team

GEO-AQ Constellation



Graphic: NASA LaRC
NO_2 Image: KNMI/ESA

CEOS Committee on Earth Observation Satellites



Launching in 2023

TEMPO Mission Leads:

Principal Investigator:

Kelly Chance, Smithsonian Astrophysical Observatory

Instrument Development:

Ball Aerospace & Technologies Corporation

Project Management:

NASA/Langley Research Center

http://tempo.si.edu/

Provides hourly daylight observations to capture rapidly varying emissions & chemistry important for air quality

- Key tropospheric pollutants measured
  - Tropospheric ozone
  - Ozone Precursors: **nitrogen dioxide (NO_2)** and formaldehyde (HCHO)
  - Aerosol optical depth
- Distinguishes boundary layer from free tropospheric ozone

Model-simulated NO_2. Warmer colors indicate larger amounts.

NASA-Associated Air Quality Remote Sensing Campaigns 2011-Present

Base Map: S5P TROPOMI Oversampled NO_2
April 2018-March 2019
Data provided by Henk Eskes/KNMI

1: DISCOVER-AQ Maryland 2011
2: DISCOVER-AQ California 2013
3: DISCOVER-AQ Texas 2013
4: DISCOVER-AQ Colorado 2014
5: Korea-US Air Quality (KORUS-AQ) Study 2016
6: Lake Michigan Ozone Study (LMOS) 2017
7: Student Airborne Research Program (SARP) 2017
8: Ozone Water-Land Environmental Transition Study (OWLETS)-1 2017
9: Ozone Water-Land Environmental Transition Study (OWLETS)-2 2018
10: Long Island Sound Tropospheric Ozone Study (LISTOS) 2018
11: Fire Influence on Regional to Global Environments and Air Quality (FIREX-AQ) 2019
12: Michigan Ontario Ozone Source Experiment (MOOSE) June 2021
13: TRACER-AQ (September 2021)
14: GEMS Validation (Oct-Nov 2021)

5, 14
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Google Earth

Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
Data LDEO-Columbia, NSF, NOAA

1 — *Tropospheric NO_2 x 10^{15} molecules cm^{-2}* — 10

N

2700 km

What is TRACER-AQ?

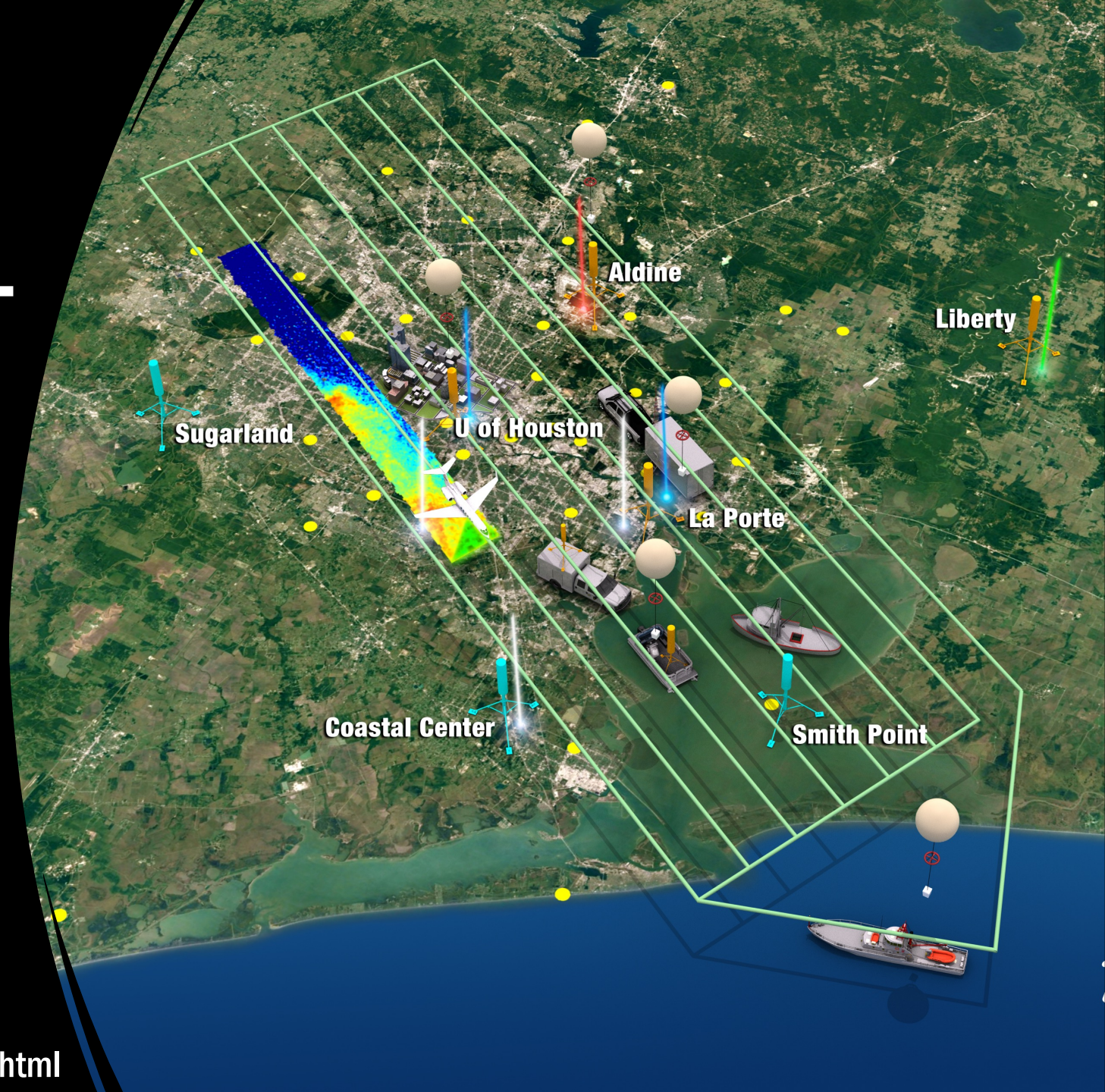
Tracking Aerosol Convection interactions ExpeRiment (TRACER) – led by DOE/Mike Jensen

Comprehensive in situ and remote sensing observations of clouds, aerosols, precipitation, radiation and meteorology

TRACER-AQ is a NASA-led air quality component with partners from TCEQ and a number of academic institutions with observations from aircraft, boats, mobile labs, and ground sites.

TRACER-AQ Science Focus Areas:

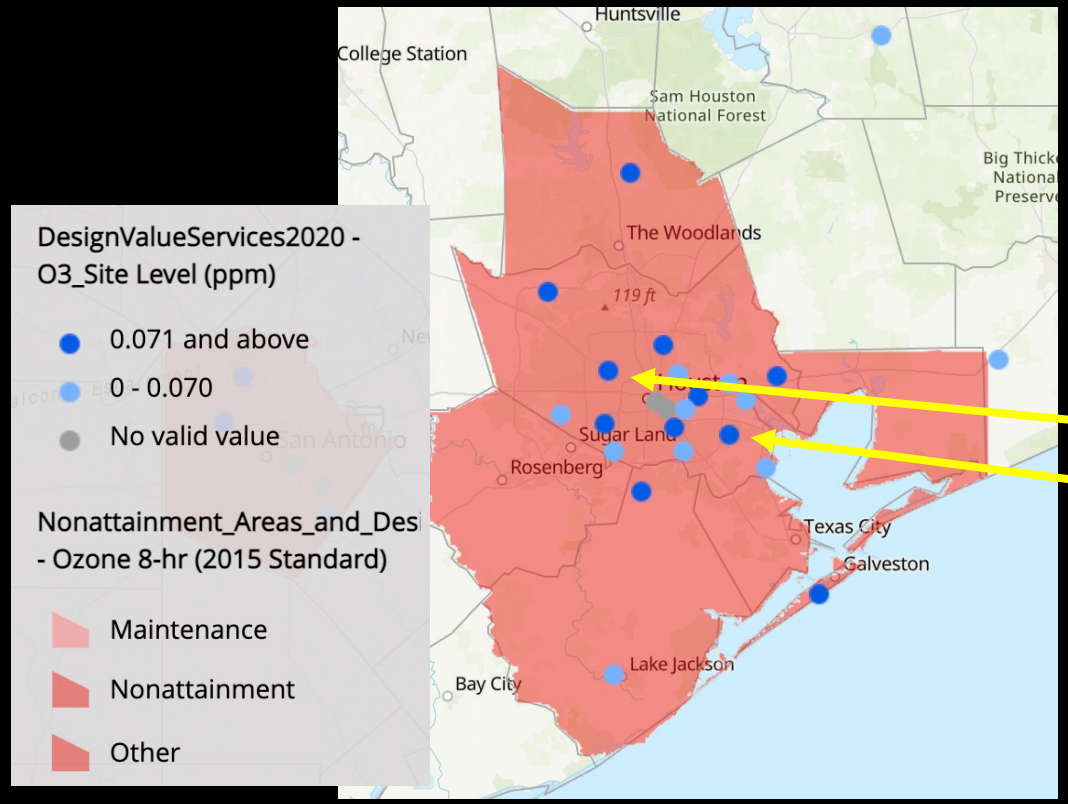
1. Ozone Photochemistry and Meteorology
2. Modeling and Satellite Evaluation
3. Intersection of Air Quality and Socioeconomic Factors

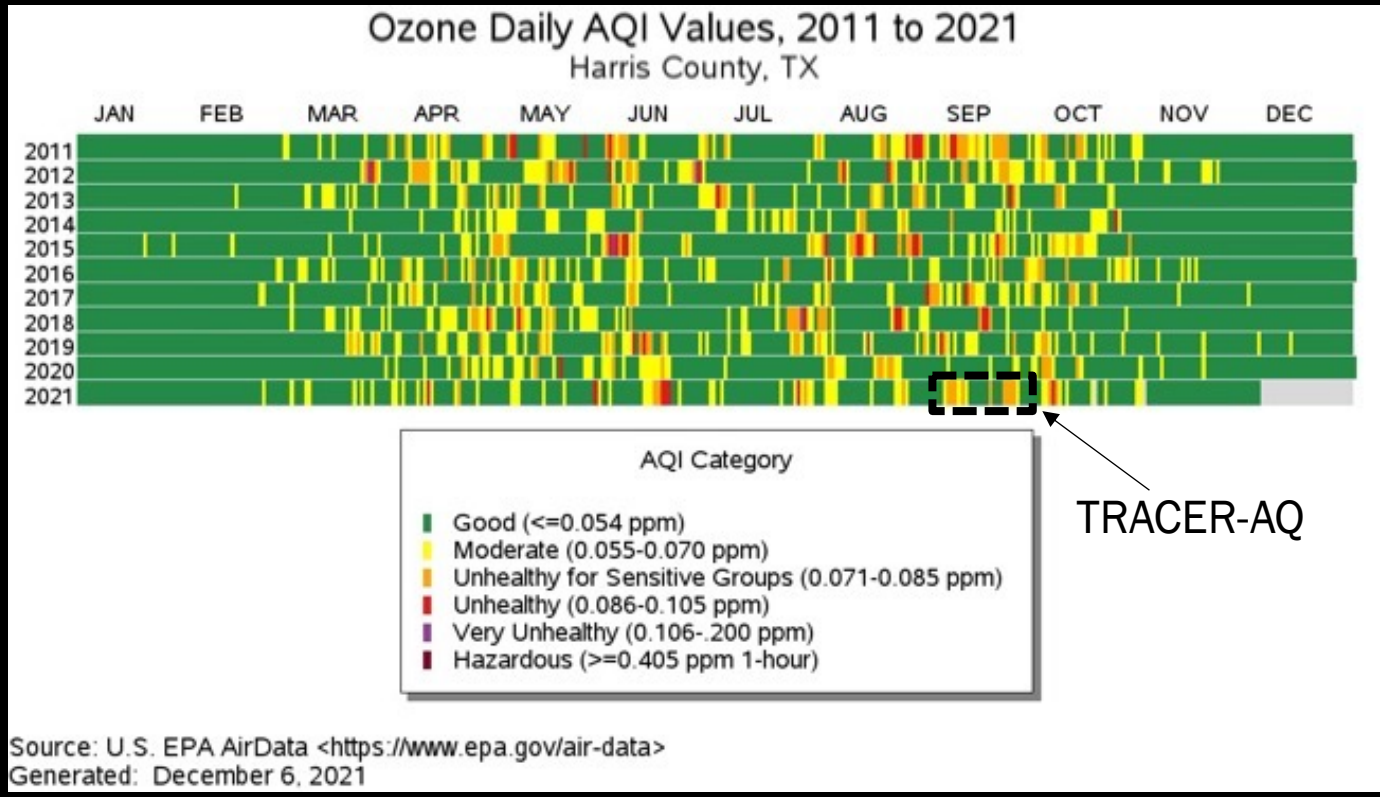


https://www-air.larc.nasa.gov/missions/tracer-aq/index.html

Houston Air Quality

The Houston area is classified as nonattainment with a marginal classification for the 2015 8-hr ozone standard and nonattainment with a serious classification for the 2008 ozone standard.





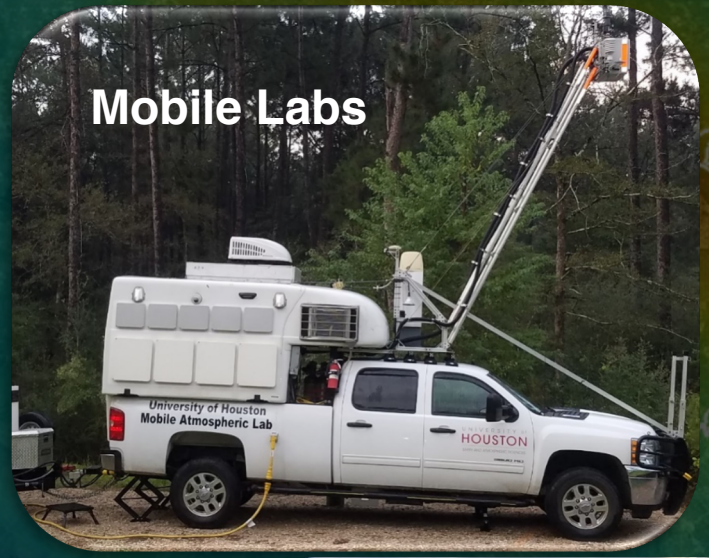
Note: bi-model distribution in high ozone AQI in Houston

Highest design value is 79 ppbv at Aldine as of 2020

Followed by Deer Park #2 at 78 ppbv

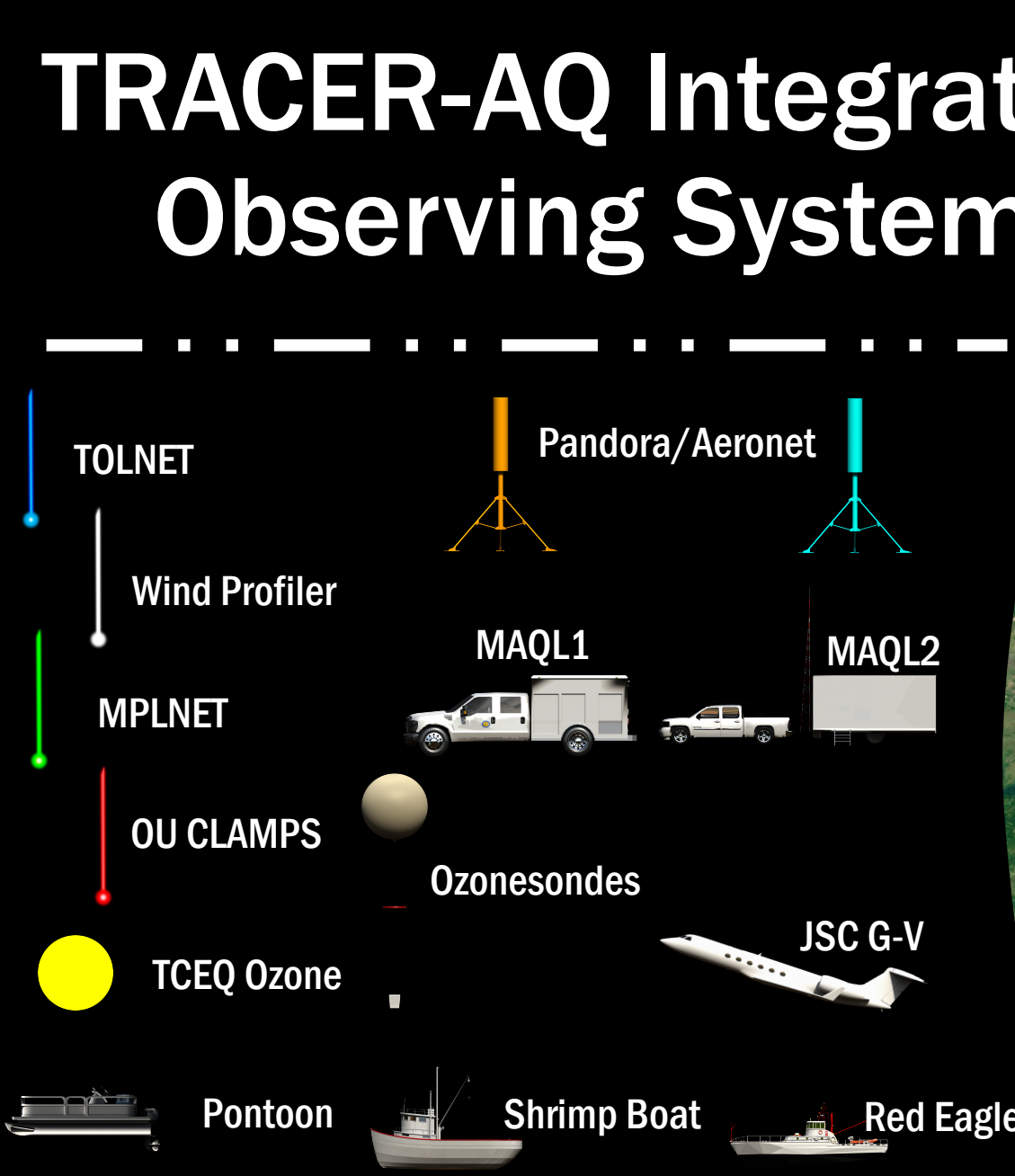
Map: https://epa.maps.arcgis.com/apps/MapSeries/index.html?appid=bc6f3a961ea14013afb2e0d0e450b0d1

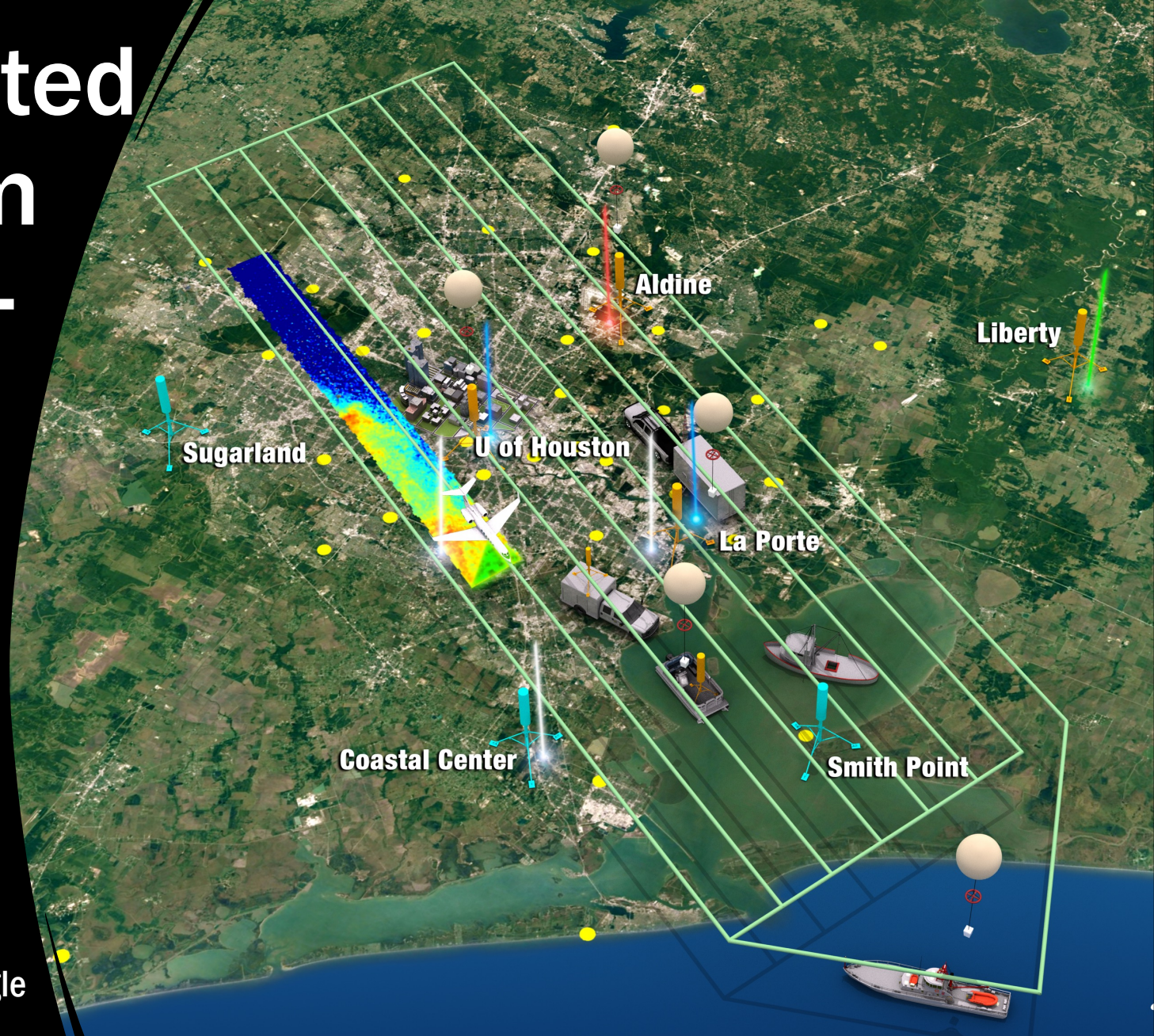
TRACER-AQ Snapshots



Not Pictured: GMAO and Forecast Support Team!

TRACER-AQ Integrated Observing System





This observing system would not be possible without our partners: TCEQ, DOE, Univ. of Houston, St. Edwards Univ., Baylor Univ., Oklahoma Univ, NASA

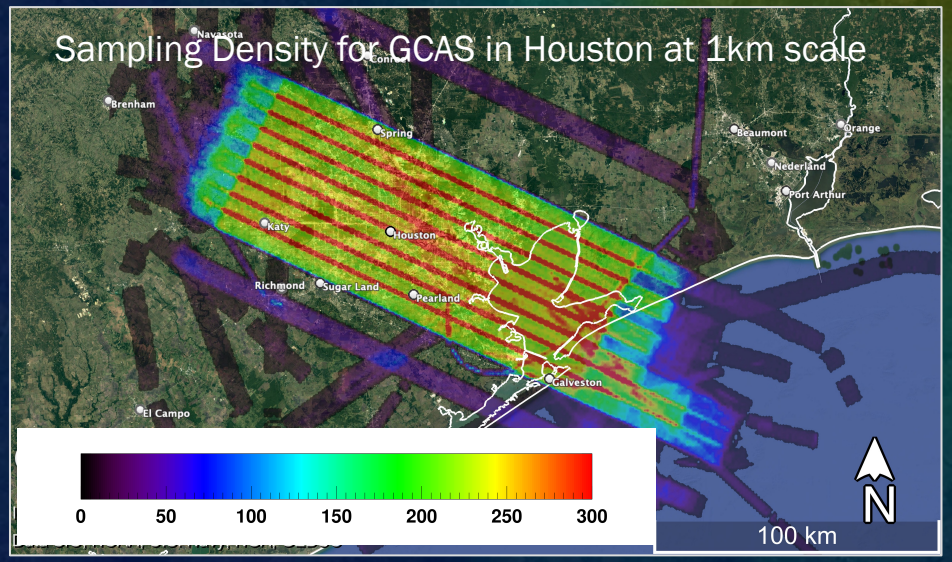
NASA JSC G-V

- Payload:
  - GCAS
  - HSRL2/DIAL

Instruments worked 100% of the time!

- Duration: 9.0-9.5 hours for a full day
  - *Used 93.3 hours over 11 flight days*
- Ground speed: 400 knots *
- Altitude: FL280 *

**can go higher and faster at the expense of spatial resolution*



Pre-flight photo
Photo credit: Laura Judd, LaRC

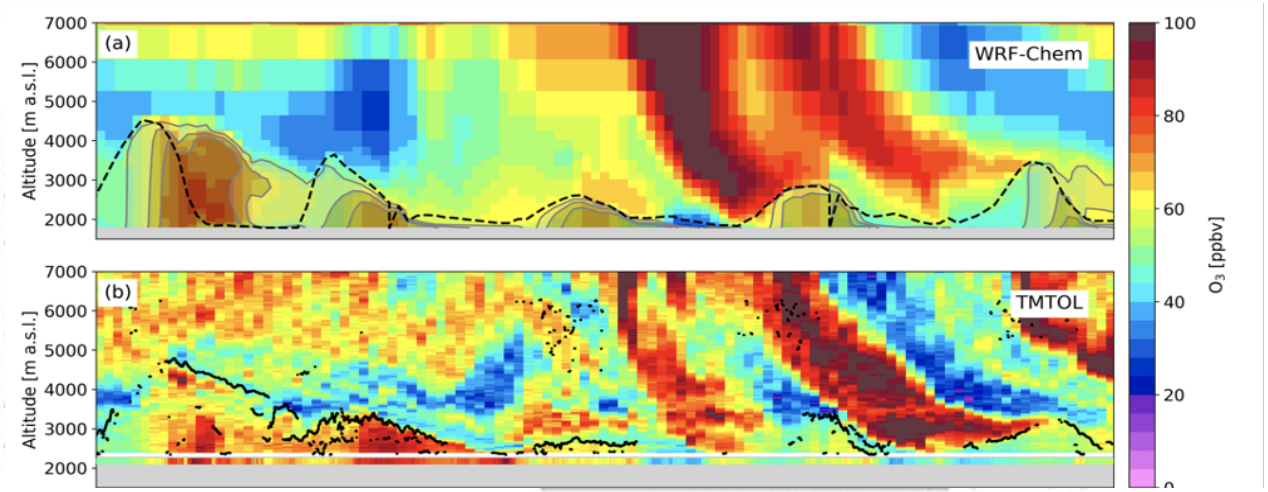
Ready to go!
Photo credit: Taylor Shingler, LaRC

TOLNet Network Overview

John Sullivan, TOLNet Project Scientist

Network Goals

1. Provide high spatio-temporal observations of planetary boundary layer (PBL) and free tropospheric ozone
2. Foster use of these high-resolution ozone observations to improve and evaluate air-quality forecast and chemical transport models used by the scientific and the regulatory community.
3. Study the atmospheric structure that current and future satellites observe and assess the fidelity with which a geostationary instrument, such as TEMPO, can measure that structure.



Network History and Evolution

TOLNet was established in 2012 to provide high spatio-temporal observations of tropospheric ozone to **(1)** better understand physical processes driving the ozone budget in various meteorological and environmental conditions, and **(2)** validate the tropospheric ozone measurements of spaceborne missions. By FY23, TOLNet expects to have 8 operational lidar systems, a modeling center, and data center.

Project Scientist: John Sullivan, NASA GSFC

Chief Scientist, Michael Newchurch, UAH

Network Map

Site	Institution
TROPOZ	NASA/GSFC
LMOL	NASA/LaRC
RO3QET	UAH
TOPAZ	NOAA/CSL
TMTOL	JPL/TMF
AMOLITE	ECCC
HU-Lidar	Hampton U.
CCNY-Lidar	CCNY
Modeling	NASA/ARC
Data Center	NASA/LaRC

Data: https://www-air.larc.nasa.gov/missions/TOLNet/

Targeted Lidar Observations for Air Quality Alerts (May 2021)

A.O. Langford, C.J. Senff, R.J. Alvarez II, S. Baidar*, B. McCarty*, S.P. Sandberg, and M. Zucker*, NOAA CSL and *CIRES, CU.*
M. Johnson, NASA-Ames, E. Knowland, NASA-Goddard, and G. Pfister, NCAR.

The TOLNet lidars have the unique ability to continuously profile ozone aloft before it reaches the surface. This example shows how targeted observations guided by model forecasts can help regulatory agencies better serve the public.

How it might work

1. **NASA-Ames** disseminates **NASA-Goddard** GEOS-CF and **NCAR** WRF-Chem ozone forecasts in daily e-mail alerts to **TOLNet** stations.

2. **TOLNet** stations make targeted observations when the forecasts predict deep stratospheric intrusions or other potential high ozone events.

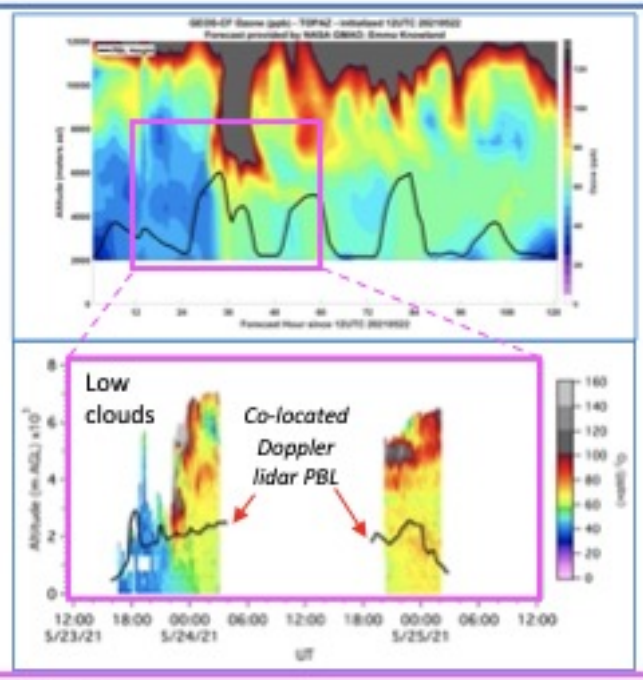
3. **TOLNet** operators advise state and local agencies to guide issuance of air quality advisories when warranted by observations.

A real life example

***TOPAZ** team alerted that WRF-Chem and GEOS-CF (right) models forecast deep stratospheric intrusion (SI) over Boulder on May 23-24, 2021.*

***NOAA-CSL** team operates **TOPAZ** lidar on May 23-24. Measurements confirm models and show entrainment of SI into the PBL on May 24.*

***TOPAZ** team notifies **CDPHE** which issues air quality advisory for affected areas. Aspen and Blackhawk monitors exceed the ozone NAAQS on May 24.*



Air Quality Health Advisory for Ozone

Issued for Clear Creek and Gilpin Counties
Issued at 3:00 PM MDT, Monday, May 24, 2021

Issued by the Colorado Department of Public Health and Environment

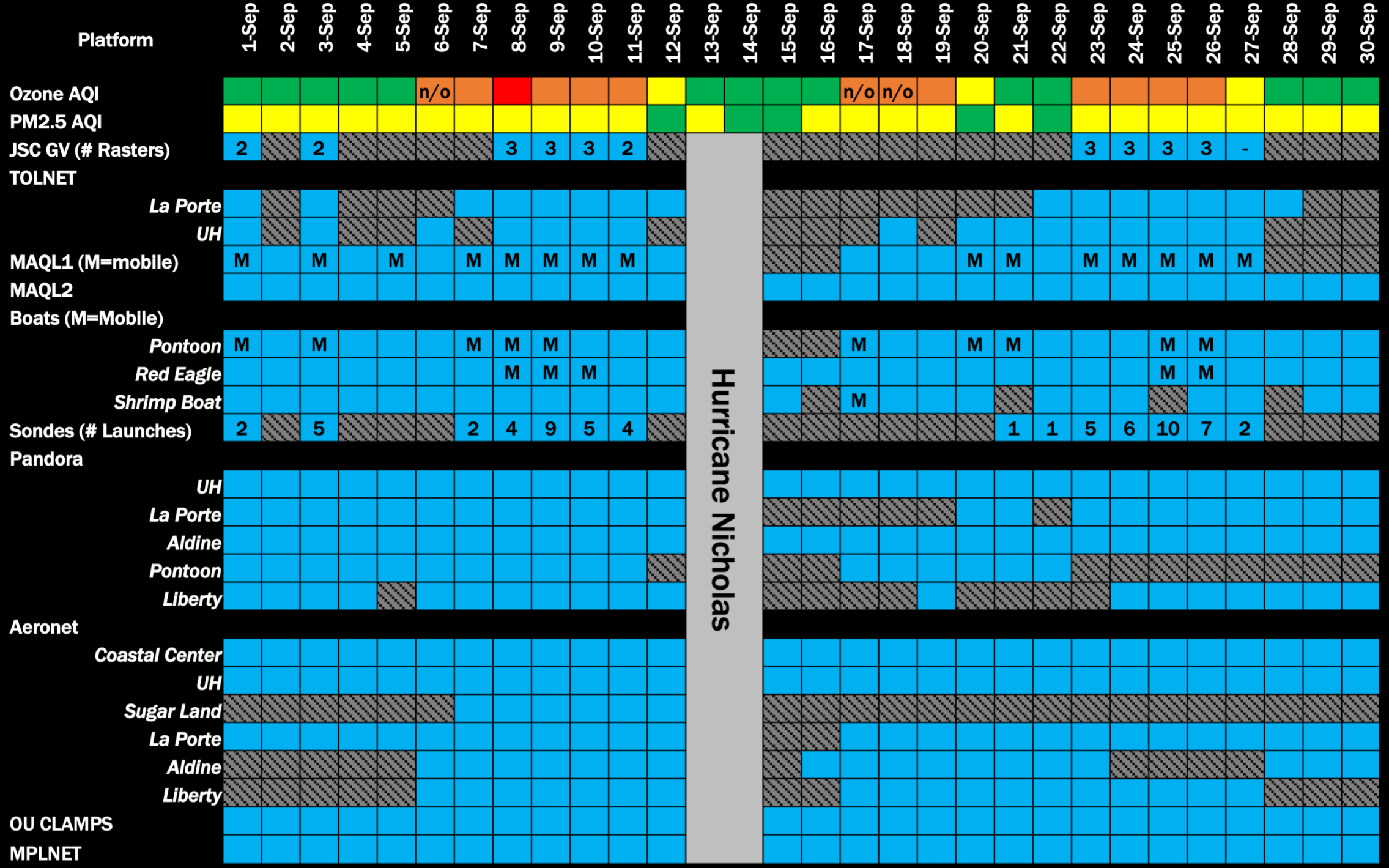
Affected Area: Clear Creek and Gilpin Counties. Cities and points of interest include, but are not limited to Georgetown, Idaho Springs, Central City, and Blackhawk.

Advisory in Effect: 3:00 PM MDT, Monday, May 24, 2021 to 12:00 AM MDT, Tuesday, May 25, 2021.

Public Health Recommendations: *Active children and adults, older adults, and people with lung disease, such as asthma, should reduce prolonged or heavy outdoor exertion within the affected areas.*

Outlook: Lingering ozone from yesterday's stratospheric intrusion will allow ozone concentrations to reach the Unhealthy for Sensitive Groups category across the advisory area, especially for locations above 8000 ft. in elevation. Ozone concentrations will likely decrease gradually late Monday evening.

COLORADO
Air Quality
Department of Public Health & Environment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Ozone AQI
PM2.5 AQI
JSC GV (# Rasters)
TOLNET
La Porte
UH
MAQL1 (M=mobile)
MAQL2
Boats (M=Mobile)
Pontoon
Red Eagle
Shrimp Boat
Sondes (# Launches)
Pandora
UH
La Porte
Aldine
Pontoon
Liberty
Aeronet
Coastal Center
UH
Sugar Land
La Porte
Aldine
Liberty
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TRACER-AQ Highlights

Focus Area 1: Ozone Photochemistry and Meteorology

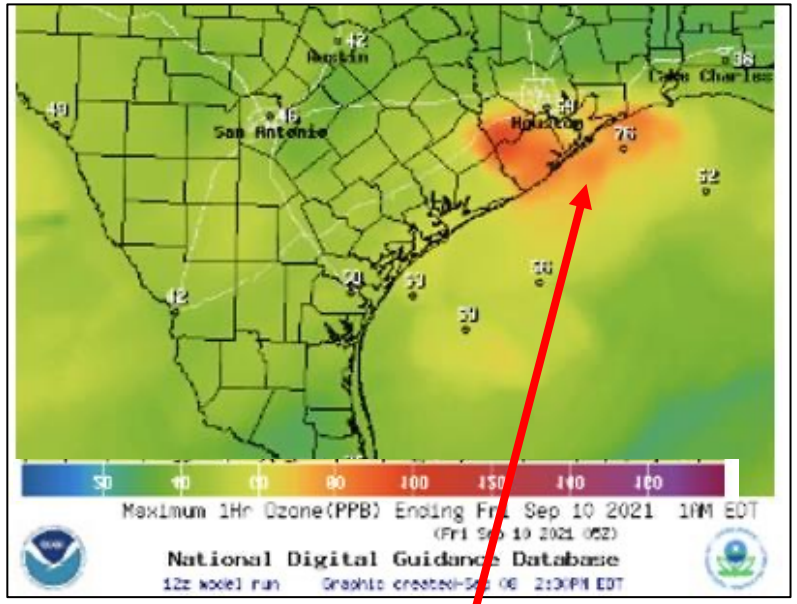
Focus Area 2: Modeling and Satellite Evaluation

Focus Area 3: Intersection of Air Quality and Socioeconomic Factors

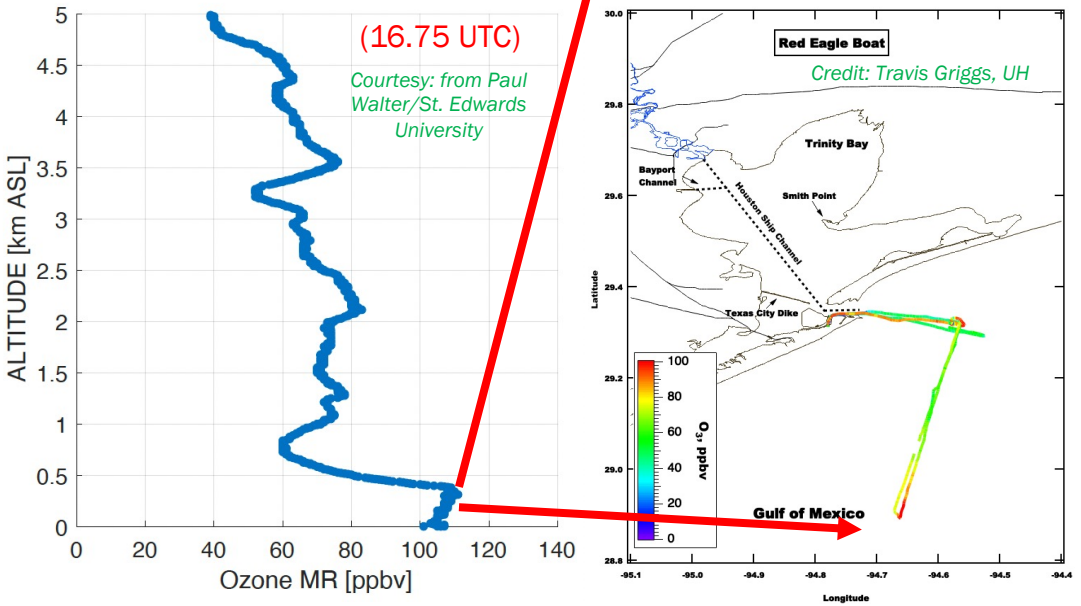
During TRACER-AQ, the data collected helped characterize the current state of ozone air quality and impact of meteorology in Houston during three separate events.

Highlights include, but are not limited to:

- ⇢ Steep horizontal and vertical gradients in ozone and precursors over land and water
- ⇢ Boat/offshore emissions
- ⇢ Influence of synoptic patterns on emission spatial patterns and providing perspective of where to expect ozone



Offshore ozone observations (sonde + in situ) September 9th, 2021



Not shown are hints of low-level ozone feature from the HSRL2 observations.

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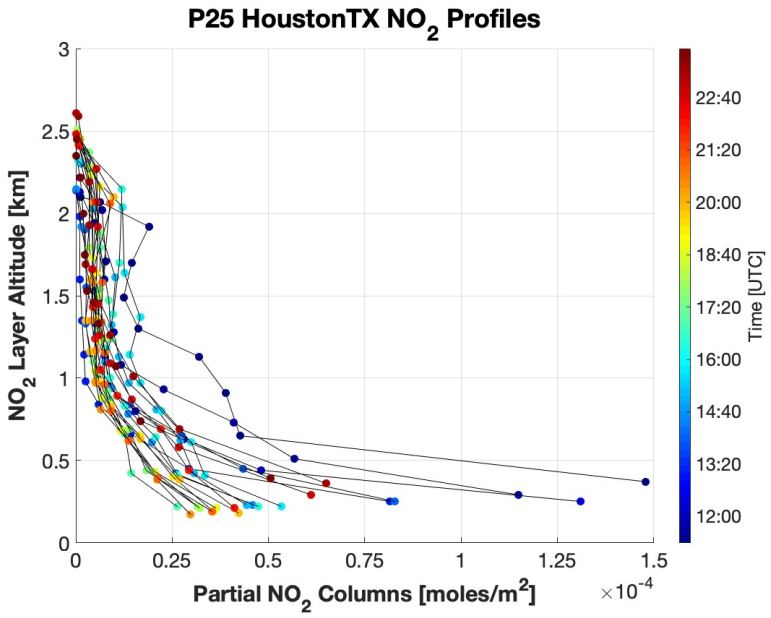
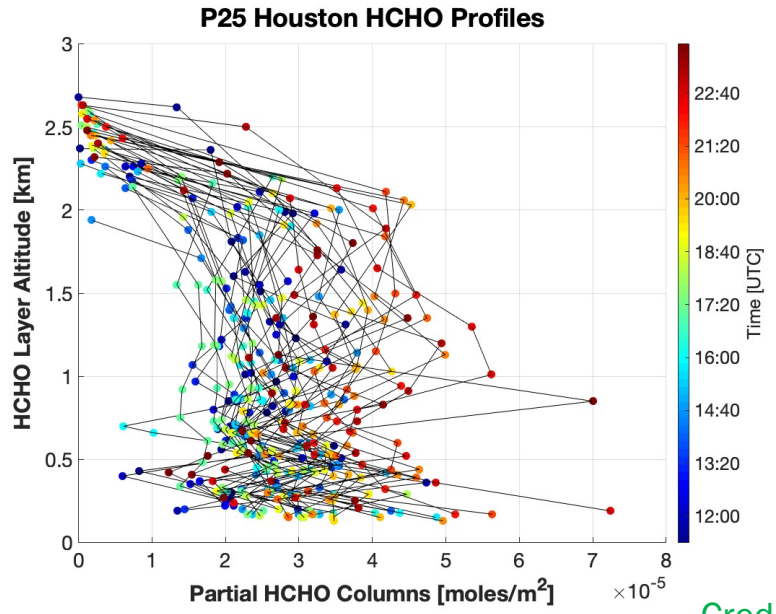
Preliminary MAX-DOAS Profiles from September 7th

https://www.pandonia-global-network.org/





Note that NO_2 and HCHO vertical distributions are quite different from each other.

⇢ NO_2 is mostly primary

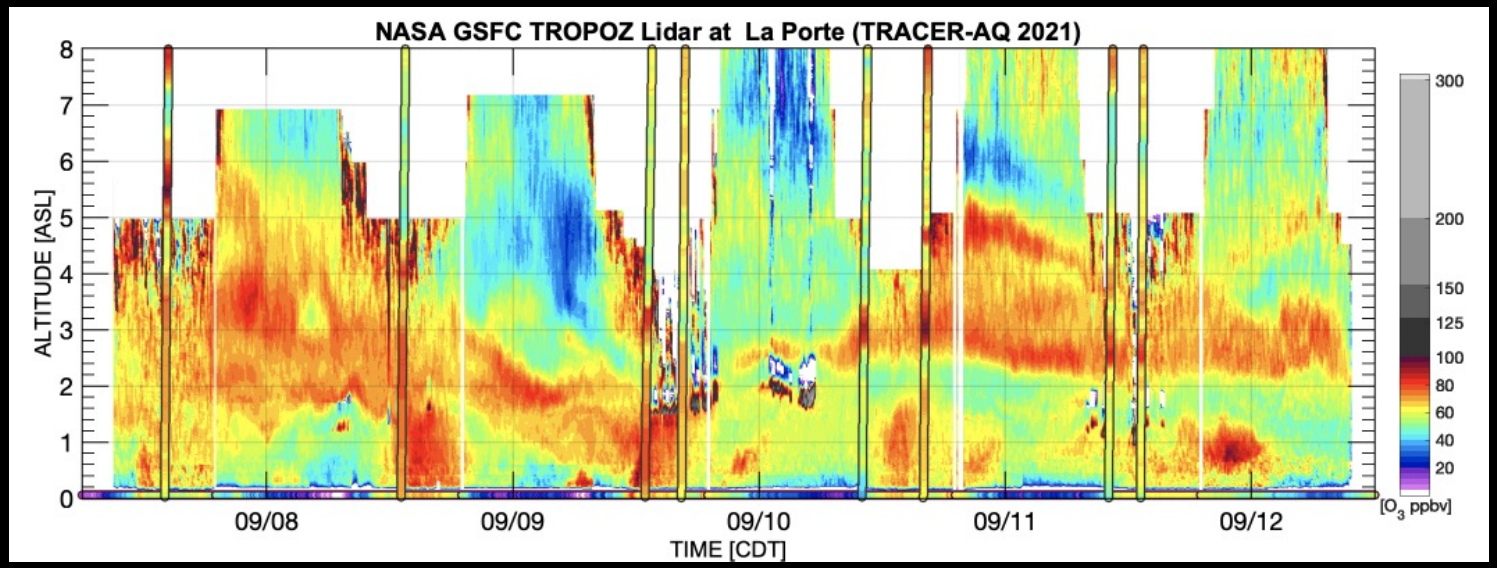
⇢ HCHO is mostly secondary

Illustrating the challenge of column HCHO:NO_2 ratio research

(NO_2 – validated
HCHO- unvalidated)

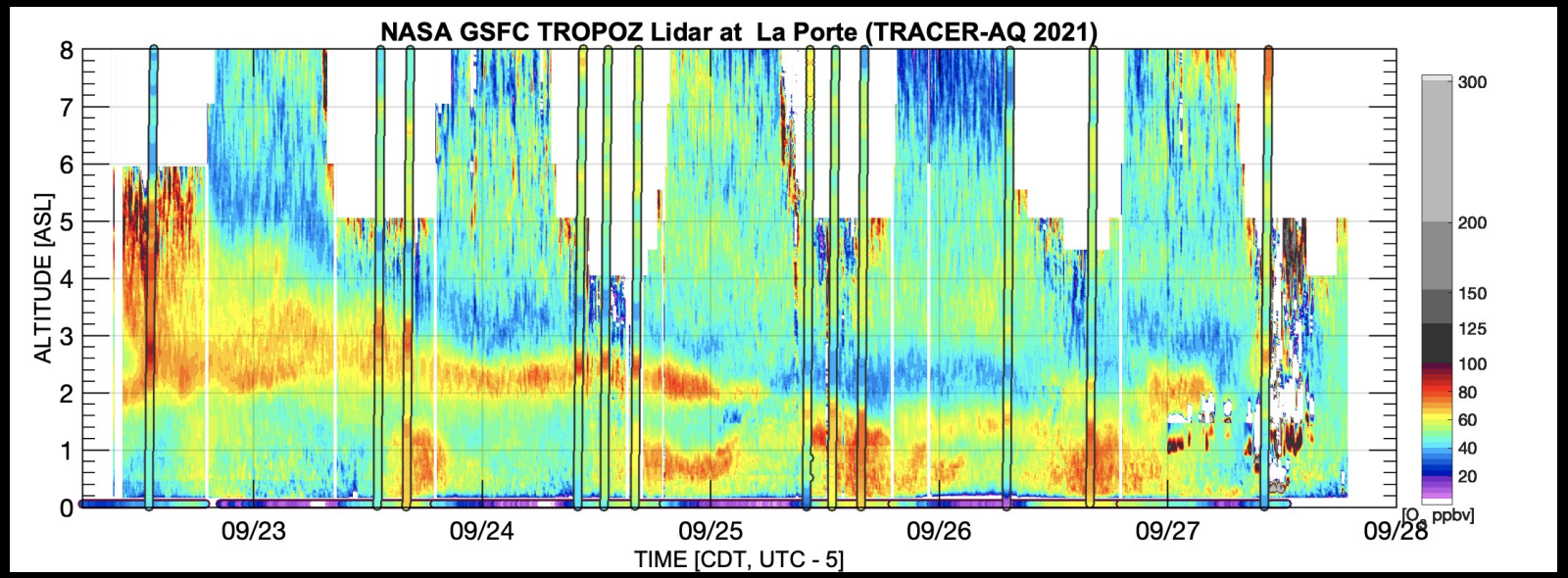
Credit: Alex Kotsakis, NASA GSFC

Highlighting Ozone With Continuous TOLNet Observations



Left, Below: Two 6 Day TOLNet ozone record, 8 ozonesonde launches.

Right: TOLNet Ozone DIAL retrievals for 8-12 Sep.



Credit: John Sullivan, w/ Support from GSFC TOLNet team

TRACER-AQ Highlights

Focus Area 1: Ozone Photochemistry and Meteorology

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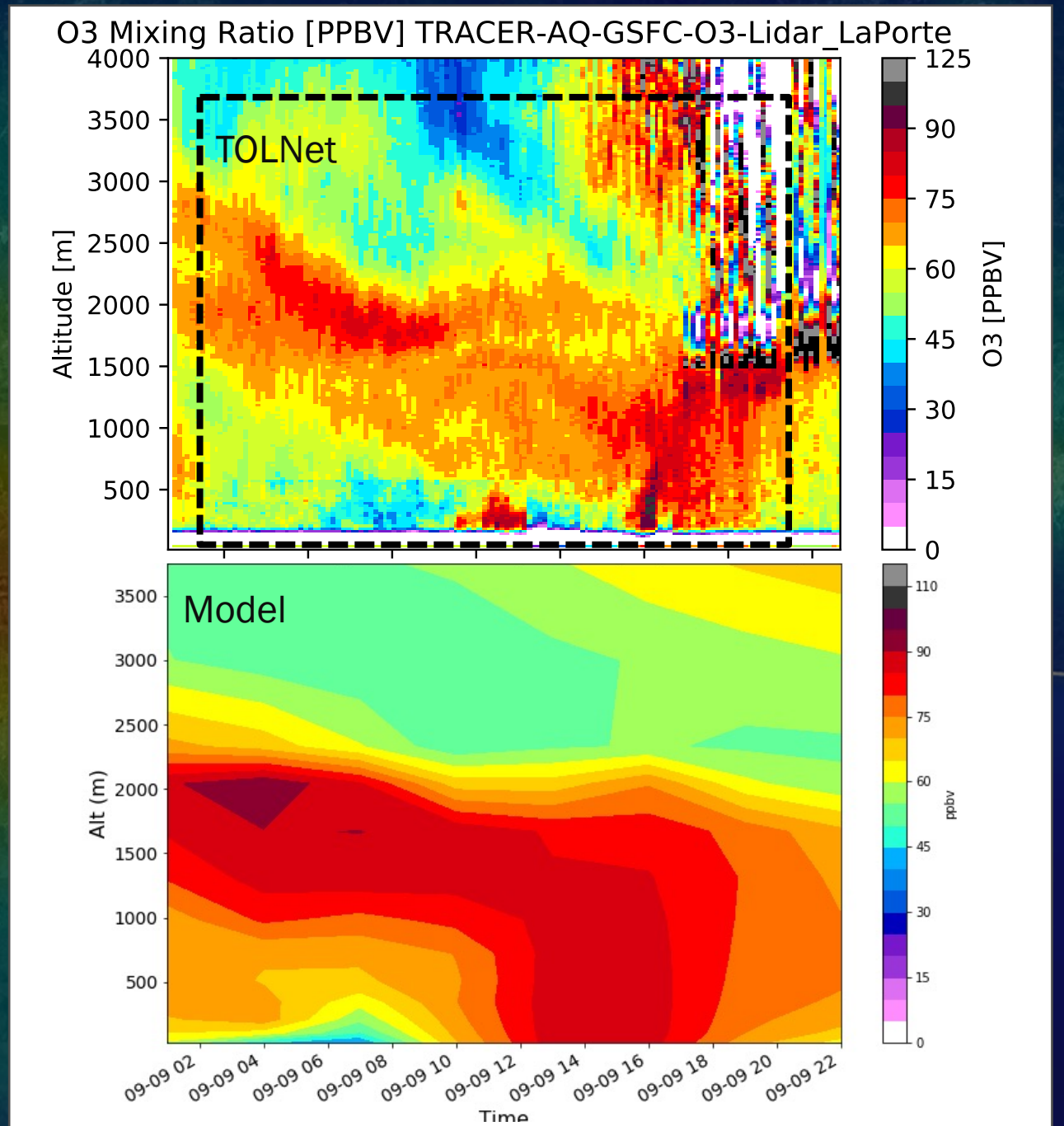
During TRACER-AQ, the data collected provide enhanced observations for evaluating air quality forecasts/models (e.g., over water ozone).

Aircraft data can also be used to create proxy-data for TEMPO for assessing the temporal evolution of O3, HCHO, and NO_2 and the impact of spatial resolution on the analysis.

These product retrievals will use GEOS-CF as a priori as a test for future TEMPO product validation/evaluations.



Preliminary Modeling (WRF-GC) Analysis of TRACER-AQ Observations –Yuxuan Wang (UH)

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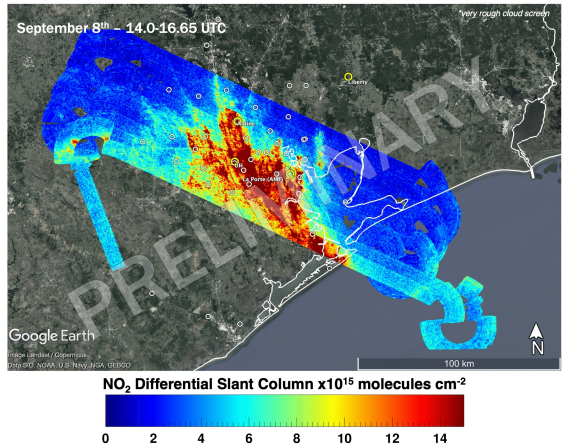
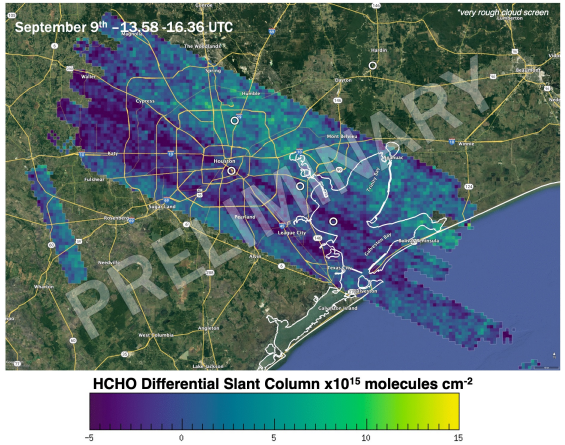
During TRACER-AQ, the aircraft collected 27 raster maps over the Houston area over 10 fight days and 1 over offshore platforms over the Gulf of Mexico.

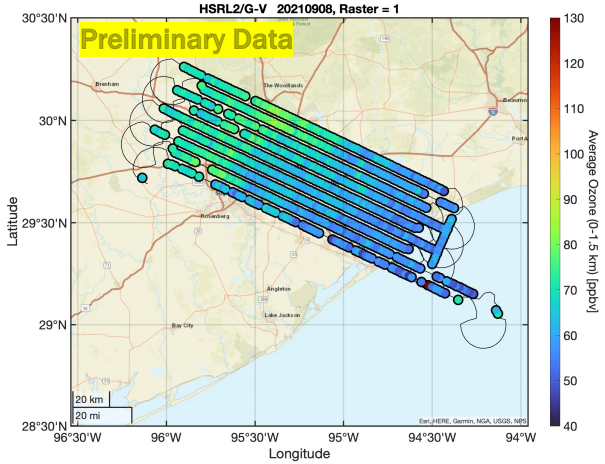
GCAS NO2 DSC



GCAS HCHO DSC



HSRL2 0-1.5km ozone



Example flight from September 8th, 2021 showing the diurnal evolution of NO_2, HCHO, and Ozone

Preliminary data courtesy of GCAS and HSRL2 teams

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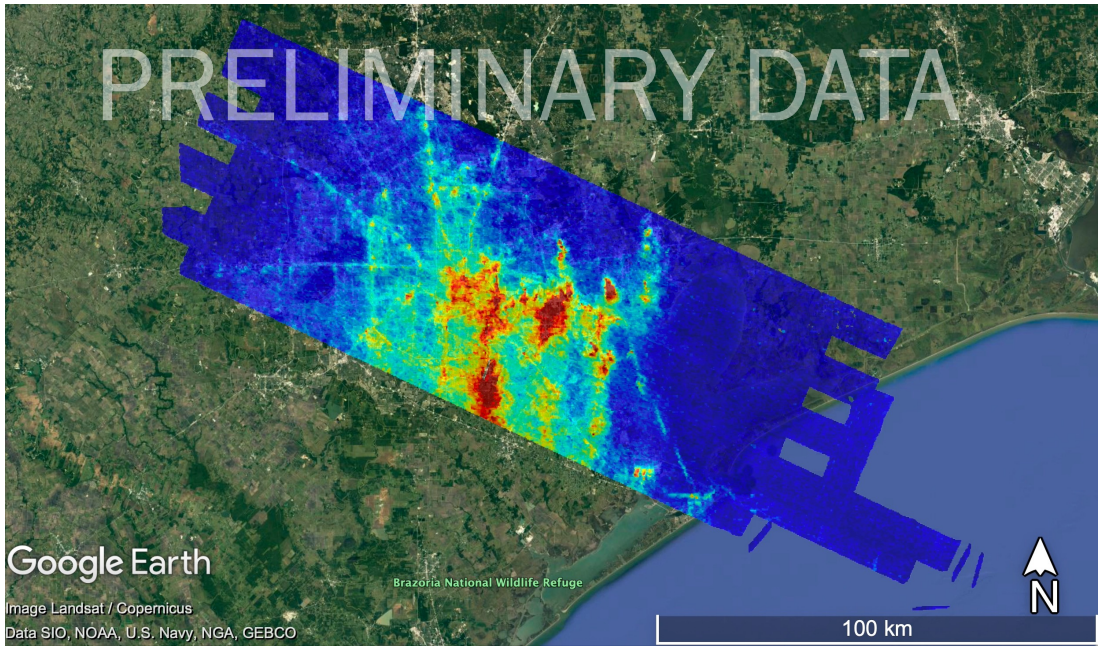

This is just one example of how this high-resolution data can be used to mimic TEMPO scale measurements.

Subset of TEMPO Presentations this week:
A11A-06, A11A-07, A25E-11

Preliminary data courtesy of GCAS team

TRACER-AQ Highlights

Focus Area 1: Ozone Photochemistry and Meteorology

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Focus Area 3: Intersection of Air Quality and Socioeconomic Factors

During TRACER-AQ, the airborne, mobile, and dense ground networks will be used to update the work of identifying air quality disparities with GCAS in Houston as documented by Demetillo et al. (2020) as well as expand analysis to HCHO and O_3.

The data collected by the instruments on the airborne platform can be used to create TEMPO proxy datasets for this analysis which expand from once per day observations with TROPOMI to how disparities evolve throughout the day.

This focus area also led to dense mobile lab sampling in the ship channel region to investigate intraneighborhood gradients

NO_2 was 37% higher for non-whites and Hispanics living in low-income tracts compared to whites living in high-income tracts in September 2013. (Demetillo et al., 2020: https://dx.doi.org/10.1021/acs.est.0c01864)

Preliminary observations from a single day in TAQ indicate that these NO_2 disparities persist throughout all times of the day.

Results with TROPOMI show that a 65% reduction in diesel NO_x emissions will reduce NO_2 inequality by 50% in Houston. (Demetillo et al., 2021:https://doi.org/10.1029/2021GL094333)

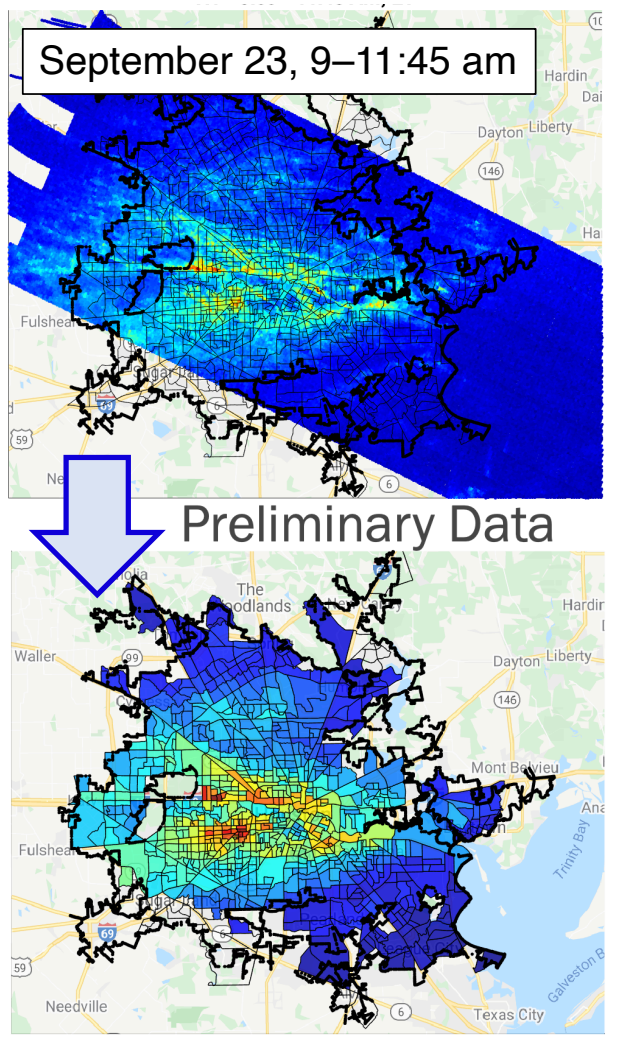
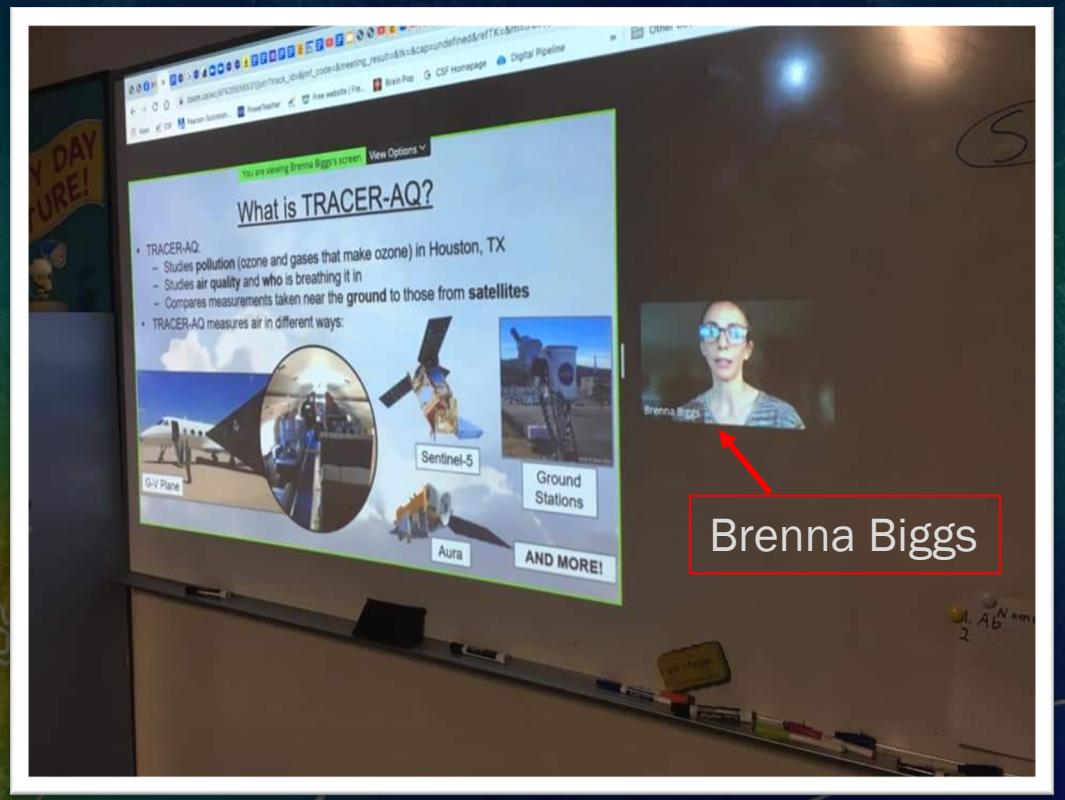


Figure demonstrates how airborne data is remapped to census tracts in Houston

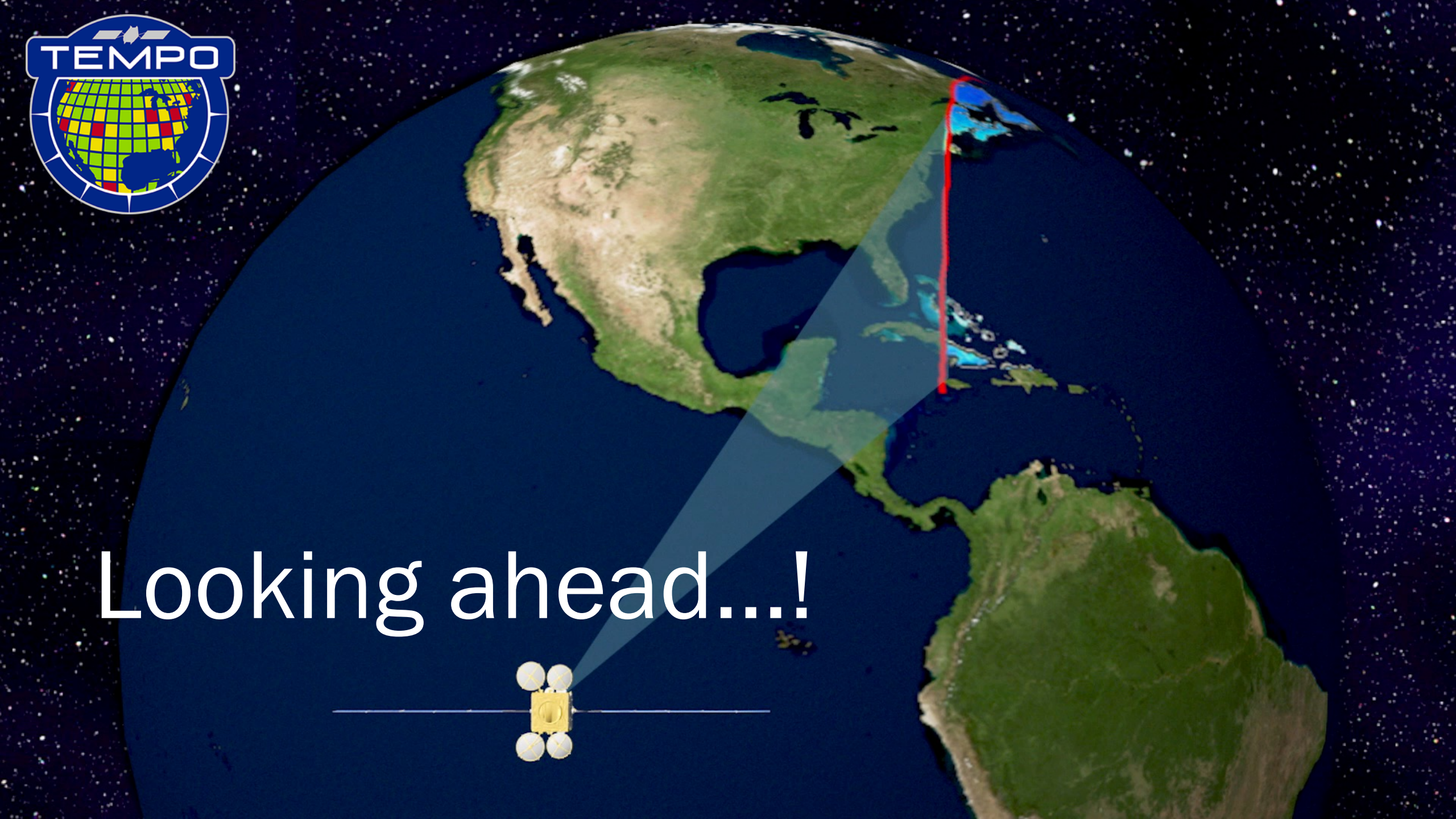
Credit for this work to Angelique Demetillo and Sally Pusede, UVA

Educational Outreach

- Led by Brenna Biggs, BAERI/NSRC
- 16 presentations at 98 schools given virtually in 5 states (CA, HI, TX, AK, NM) and 4 countries (U.S.A., Philippines, Canada, South Africa)
- 2,791 students have been reached
- 34 questions answered on MTS #ask_airborne channel
- 8 TRACER-AQ scientists involved in outreach



Media outreach:
https://www.nasa.gov/feature/langley/nasa-study-examines-houston-area-air-quality-issues/
https://appliedsciences.nasa.gov/our-impact/story/supporting-healthy-air-healthy-planet-texas-and-beyond


TEMPO
Looking ahead...!

Synergistic TEMPO Air Quality Science (STAQS) mission

In July-August 2023, STAQS seeks to integrate TEMPO satellite observations with traditional air quality monitoring to improve understanding of air quality science and increase societal benefit.

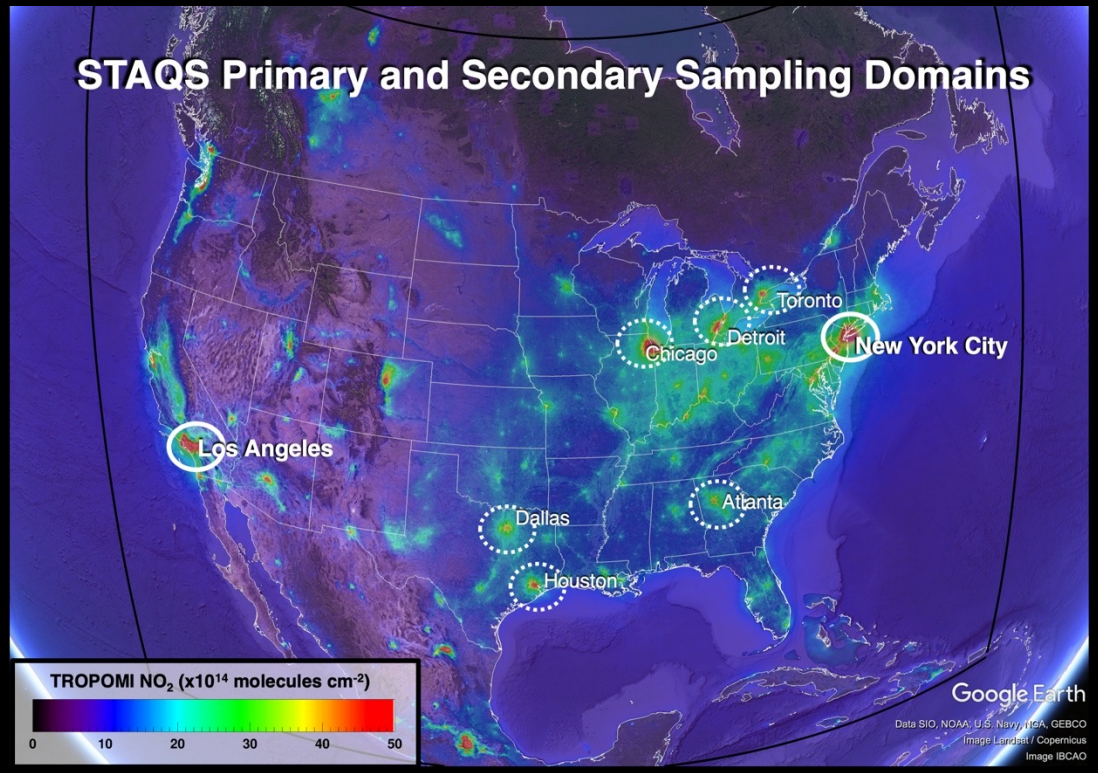
Science Objectives

1) Evaluating TEMPO level 2 products geo-physically, spatially, and temporally
2) Interpreting the temporal and spatial evolution of air quality events tracked by TEMPO
3) Improving temporal estimates of anthropogenic, biogenic, and fire emissions
4) Assessing the benefit of assimilating TEMPO data into chemical transport models
5) Linking air quality patterns to socio-demographic data

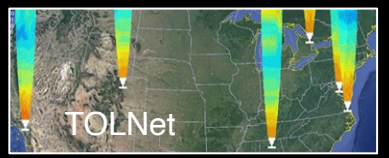
Collaborative activities:

- NOAA Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas (AEROMMA)
- NOAA Coastal Urban Plume Dynamics Study (CUPiDS)
- Greater New York Oxidant, Tropospheric Halogens, and Aerosol Airborne Mission (GOTHAAM)

Annual average of TROPOMI NO_2 overlaid with the currently planned primary (solid circles) and secondary (dotted circles) sampling domains during STAQS within the TEMPO field of regard (black outline).



Includes deployment of airborne and ground-based remote sensing observations



Interested in connecting with the STAQS team? laura.m.judd@nasa.gov and john.t.sullivan@nasa.gov

Thanks for your attention!